Economic-mathematical modeling of rational water use and minimization engineering enterprise's negative impact on the environment

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Summary. This article applies to application of economic-mathematical modeling for eco-directional control for industrial enterprises. Research was conducted on the example of the engineering enterprise "Lugansksteplovoz" in part of ensuring efficient use of water in industrial manufacturing and minimize the negative impact of enterprise activities on the environment. Mathematical model of finding the economic optimum of contaminated water cleaning in carrying out enterprise production activity was constructed.

Key words: industrial enterprise, water supply of manufacturing, unsustainable natural resource use, environmental pollution, economic and environmental damages, economic- mathematical modeling, eco-directional control.

INTRODUCTION

Industrial enterprises need significant water supply to function effectively. Water consumption of domestic production is among the highest in the world today, it is about 0.3 m3 per UAH of finished product. Actuality of the theme caused by the deepening problem of unsustainable natural resources use, leading to environmental pollution and causes significant economic and environmental damages. Major number of Ukraine's industrial enterprises were built in the USSR and most of them are highly resource-intensive, with depreciation of production equipment and obsolete or ineffective filtration technologies emissions and discharges [2, 6, 7, 11]. In such conditions the entity striving to make a profit may be followed by causing irreparable environmental damage, exceeding the standards of resources use, which is a violation of existing environmental legislation. Therefore, particularly important becomes the searching the optimal level of cleaning pollution that is formed during manufacturing process. Considerable attention should be paid to ecological and economic impact assessment of active industrial enterprises in order to regulate manufacturing processes and organizational measures to minimize their destructive effects.

OBJECT, SUBJECT AND AIM OF RESEARCH

The object of the research is manufacturing processes on industrial enterprise. The subject is the influence of manufacturing processes on the environment. The main aim of the research is the implementation of environmentally oriented enterprise management to minimize the negative influence of its activities on the environment and development of approaches to the regulation of water use in the industrial production.

RESULTS OF RESEARCH

Diversified economic complex established in Ukraine requires the use of many natural resources. One of the most important natural resource that defines the location of the productive forces is water, and very often it is also the means of production. Industrial enterprises need significant water supply [20]. The main impact of water use on water resources is conditioned by rotation-free water intake and discharging pollutants into water bodies. Therefore it is especially important to research the influence of manufacturing processes on water bodies in order to maintain optimal water environmental indicators and reduce ecological-economic damage from the industry impact on the environment. Industry represents 58% of the total volume of contaminated wastewater. The main sources of water pollution are enterprises that are pulp and paper industry, chemical, production of coke, petroleum, mining iron ore, coal, metallurgy industries and mechanical engineering. For example, Fig.1 shows how the volume of wastewater discharging is distributed by branches of economy Lugansk region [1].

Engineering enterprises' runoffs in the Luhansk region have significant influence on surface water bodies. The causes of pollution of water resources are the lack of wastewater treatment before its discharging into rivers or sewage system. Wastewater etching and plating plants polluted by petroleum products, sulfates, chlorides, suspended solids, cyanide, nitrogen compounds, salts of iron, copper, zinc, nickel, chromium, molybdenum, phosphorus, cadmium [1, 5, 8]. Heavy metals, radionuclides and other solid waste aren't disposed of or re-processed and thereby cause harmful effects on the environment [5, 9].

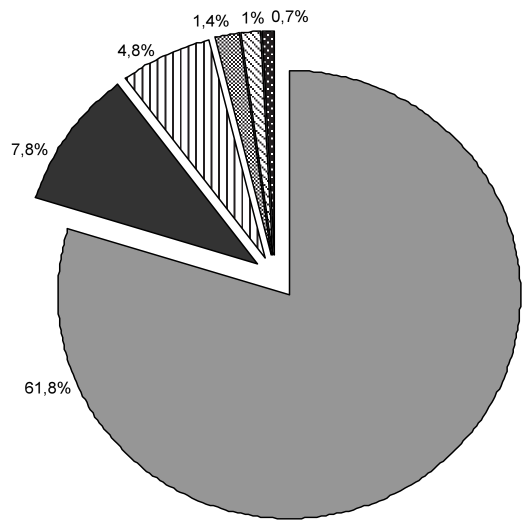


Fig. 1. The volume of wastewater discharging by branches of industry Lugansk region:

– coal industry,
– chemical and petroleum industry,
– power industry,
– mechanical and metalwork industry,
– metallurgy,
– pulp and paper industry.

One of the industrial enterprises, working in mechanical engineering and provides wastewater discharges to the river Lugan is public joint stock company "Luganskteplovoz". Research was conducted on this enterprise. "Luganskteplovoz" as the enterprise with significant production volume, according to the law of Ukraine "On Environmental Protection" [10] and other legal documents in the sphere of environment should closely monitor the processes that affect the environment. Department of environmental protection is division dealing with industrial area environmental monitoring [12, 19].

Manufacturing processes of machine-building enterprises are characterized by high levels of environmental pollution. These processes include: in-plant energy production and other processes that involve combustion of fuel, foundry production, metal working structures and components, welding production, refinishing products. At the plant in order to reduce concentration of pollutants wastewater treatment plants and installation of water treatment are set. They are used before discharging wastewater into water bodies. The main type of industrial wastewater treatment facilities is mechanical oil traps. Mechanical cleaning allows to allocate 70-80% insoluble impurities from industrial waste water.

Average values for each of the pollutants in wastewater "Luganskteplovoz" and their comparison with the approved standards maximum permissible discharge (MPD) are shown in Table. 1 [13]. Data table shows that results of 11, 14 water outlets and rotating stop valve water outlet exceed the maximum permissible discharge of pollutants. This can demonstrate that there is a need to establish additional treatment facilities at some water outlet or necessity manufacturing processes redesign to reduce the concentration of pollutants in the water.

Table 1. Comparison of actual discharges with the standards MPD

	water outlet 4			water outlet 9			water outlet 11			water outlet 12		
	actual g/year	MPD	excess	actual g/year	MPD	excess	actual g/year	MPD	excess	actual g/year	MPD	excess
suspended matter	41,6	90	-	157,08	115,5	41,58	1144	924	220	820	1982,5	-
mineralization	2641,6	5400	-	8085	6930	1155	93184	63000	30184	36660	118959	-
nitrogen	0,5	1,404	-	1,8018	1,8018	-	20,28	16,38	3,9	8,04	31,72	-
nitrity	0,195	0,54	-	1,155	1,155	-	18,2	14,7	3,5	2	11,895	-
nitrates	68,9	162	-	184,8	184,8	-	1560	1470	90	700	2775,5	-
sulfates	67,3	1800	-	2310	2310	-	26000	21000	5000	10600	39650	-
chlorides	5,81	1260	-	1617	1617	-	18200	14700	3500	7600	27755	-
oil	0,381	1,08	-	7,67	1,386	6,284	15,6	12,6	3	6,03	23,79	-
phosphates	4,445	12,6	-	9,24	9,24	-	104	84	20	40,2	158,6	-
iron	8,5	1,08	7,42	1,386	1,386	-	15,6	12,6	3	7	23,79	-
zinc	0,91	2,52	-	5,36	4,62	0,74	51,87	42	9,87	22	79,3	-
copper	0,045	0,126	-	0,1386	0,1386	-	1,716	1,386	0,33	0,66	2,6169	-
nickel	0,065	0,18	-	0,2772	0,2772	-	5,187	4,2	0,987	1	3,965	-
aluminum	0,381	1,08	-	1,57	1,385	0,185	13	10,5	2,5	4	15,86	-
chrome	0,0127	0,036	-	0,05544	0,05544	-	8,32	6,72	1,6	0,4	1,586	-
	water outlet 13			water outlet 14			water outlet 15			water outlet rotating stop valve		
	actual g/year	MPD	excess	actual g/year	MPD	excess	actual g/year	MPD	excess	actual g/year	MPD	excess
suspended matter	1164,8	193	971,8	7426	1193,25	6232,75	5621	3075	2546	870	633,25	236,75
mineralization	11200	44580	-	90522	76368	14154	64970	184500	-	50750	37995	12755
nitrogen	57,6	15,4	42,2	470	9,46	460,54	18,25	61,5	-	87,21	50,66	36,55
nitrity	1,6	1,93	-	9,4	0,946	8,454	5,5	18,45	-	6,3	17,731	-
nitrates	128,6	154,4	-	940	954,6	-	1168	4305	-	1305	1139,9	165,15
sulfates	3215	3860	-	25615	23865	1750	18250	61500	-	14535	12665	1870
chlorides	2250,5	2701	-	18800	16705,5	2094,5	129575	43050	86525	10175	8865,5	1309
oil	8,7	2,316	6,384	80,37	14,32	66,05	57,305	36,9	20,405	8,721	7,6	1,121
phosphates	12,86	15,44	-	94	95,46	-	73	246	-	58,14	50,66	7,48
iron	33,92	3,86	30,06	14,1	14,32	-	10,95	36,9	-	29,07	12,665	16,405
zinc	7,94	7,72	0,22	51,7	47,73	3,97	40,15	123	-	44,95	25,33	19,62
copper	0,41	0,49	-	1,974	2,005	-	1,314	4,428	-	0,899	0,7852	0,1138
nickel	0,256	0,31	-	2,82	2,864	-	1,387	4,674	-	0,63	1,7731	-
aluminum	1,8	2,162	-	41,36	23,865	17,495	29,2	61,5	-	6,96	6,08	0,88
chrome	0,11	0,131	-	0,611	0,6205	-	0,584	1,968	-	0,522	0,456	0,066

The enterprises economic performance substantially depends on the value of the damages to the environment [15 - 18]. Economic-mathematical models construction provides an opportunity to give assessment of industrial enterprise influence on both economically and environmental indexes. The enterprise's management will be able to regulate the manufacturing processes in a way that will be optimal economic development level achieved with the lowest possible influence on environment based on the obtained results by model.

Suppose that there is one source that empty one type of pollutant in the water body.

Introduce the notation:

D – production volume, (units),

$S(D)$ – volume of polluted with D-production volume, (mg/l),

$Z(X)$ – the cost of cleaning X-volume of pollution, where X takes values $0<X\leq S(D)$, (conventional money units),

U(S-X) – costs formed by dumping (S-X)- pollution volume (conventional money units),

X – volume of pollution cleared, (mg/l or mg/dm3).

The total volume of contaminated water that enterprise forms may partially or completely cleaned by treatment facilities.

The enterprise can't cleanse more pollution than the total volume of contaminated water S, which is shown as a vertical line in Fig. 2. Hence, the obtained restriction $0 < X \leq S(D)$.

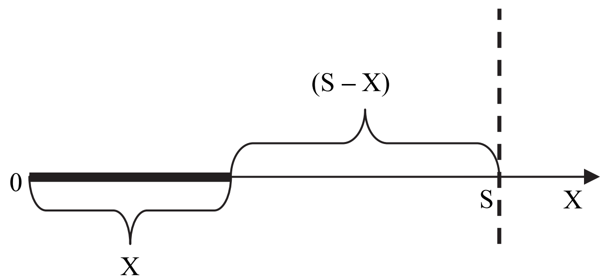


Fig. 2. The volume of treated water *X* in the total discharges *S*

The legislation sets a certain level of pollution, which may include waste water, which does not lead to violations of environmental and human health, it is call maximum allowable concentration (MAC) [14]. Let's put allowed level of pollution as VMAC. The volume of contaminated wastewater that needs mandatory clearing to achieve MAC standards, marked as XMAC, from this XMAC=S–VMAC. If D-production volume in the enterprise is high, the wastewater formation will grow. This would increase pollution in wastewater discharges and harmful substances possibly greater than set level V_{MAC} (Fig. 3).

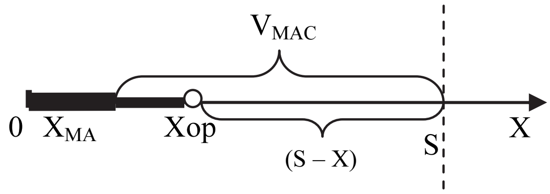


Fig. 3. Volume of pollutants that exceeds MAC level

In order to achieve MAC standards mandatory minimum volume X_{MAC} of polluting substances should be cleaned. Also, it is necessary to predict the additional volume of clearance in the range of (X_{MAC}, X_{opt}). The optimum level of cleaning X_{opt} is within $X_{MAC} < X_{opt} \leq S(D)$. Value X_{opt} reduces their negative impact on the environment and the cost of dumping pollutants into the pond U(S-X). Fee for violating MAC can be increased by 5 times maximum according to Ukrainian legislation (or gradually from 1 to 5) [3, 4]. If at the enterprise there is no limits of emissions and discharges of pollutants approved in the prescribed manner, fee is charged as per above-limit discharges [12].

Thus, for each production volume D applies follows dependency (Fig. 4). Conventionally, it is possible to consider given dependencies for fixed production volume D, which further will be denoted in the calculation as upper index.

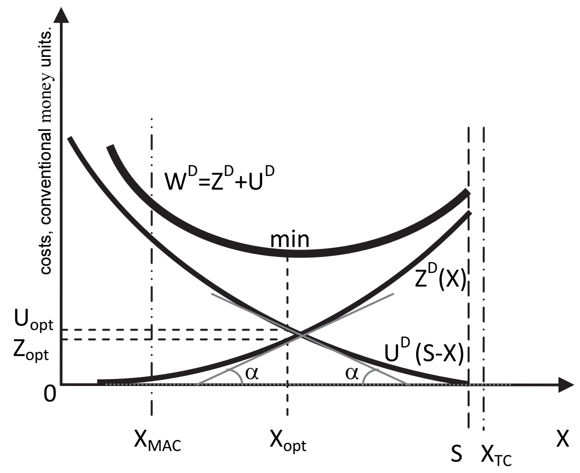


Fig. 4. Graphic representation of economic-mathematical model of achievement standards MAC and economic optimum pollution

Increase *X* treated wastewater will reduce the cost U=S-X of dumping pollutants into the water bodies. Along with the reduction of costs formed by dumping (S-X)-pollution volume, there is an increase costs Z for wastewater treatment.

Total costs are formed from costs of cleaning and the cost of dumping pollutants, note them as $W^D(X)$ and it can mathematically expressed as:

$$W^D(X) = Z^D(X) + U^D(S - X).$$

Minimum of function (Fig. 4) corresponds to a point that results in the condition:

$$\frac{\partial W}{\partial X} = 0 .$$

Mathematical model was built for regulation the interaction of enterprises with the environment, taking into account the economic interests of the enterprise. This model may be the basis for tracking the achievement of the eco-management system on an industrial enterprise.

The purpose of modeling is searching optimal volume cleaning X_{opt} at which the minimum total cost W, related with pollution and the costs of cleanup.

Value of X pollution cleaned is limited technical capabilities of installed treatment plants, mark it as X_{TC}.

By giving different values of production volumes the proposed model can be used in dynamics. For management of the enterprise it will enable to determine the production volume in which it receives economic profit and has minimum possible negative influence on the environment.

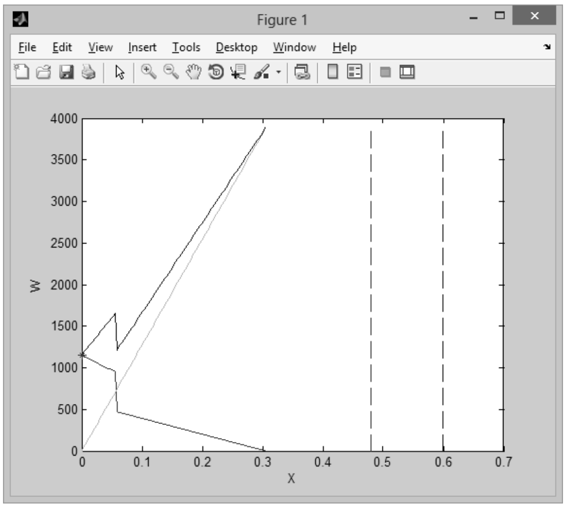
Calculations were made with the understanding that the waste water can be treated only of oil by oil trap, so pollution means the oil content.

Legally allowed to dump oil into the reservoir equal to 0.2008 tonnes per annum [13]. If the volume of polluted more than the allowed amount (equal 0.2008 MAC) than environmental payments increases depending on the excess, up to 5 times [4].

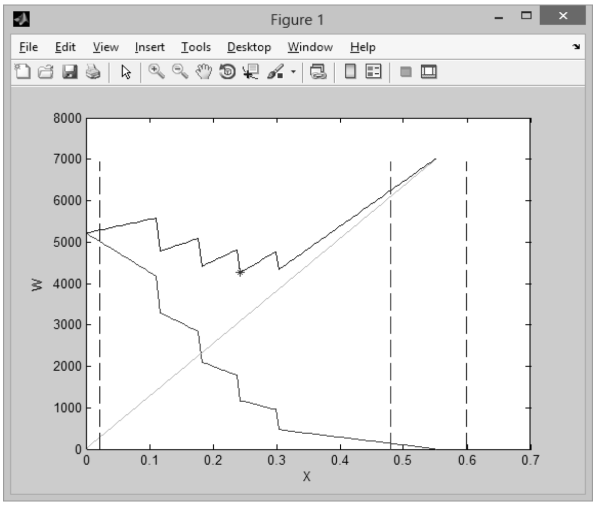
According to statistical data of enterprise dependence between waste formation and production volume was found. It's like polynomial y = -6E-06x2 + 0.0037x + 0.1058. Even with a minimum production volume a certain volume of pollution will be formed.

Searching for the optimal level of contaminated wastewater enterprise and visualization of results software package MATLAB [21] applied.

Approbation results of economic-mathematical model for "Luganskteplovoza" are shown in Fig. 5. Thus, the production of 40 units of output produced relatively few pollutants. The company still has a reserve of polluted because statutory limit is not exceeded. In this case, economically this volume of pollution dump to water bodies without a clearance. The company pays a regular tax rate, cost is about 1200 UAH (Fig. 5a).



a



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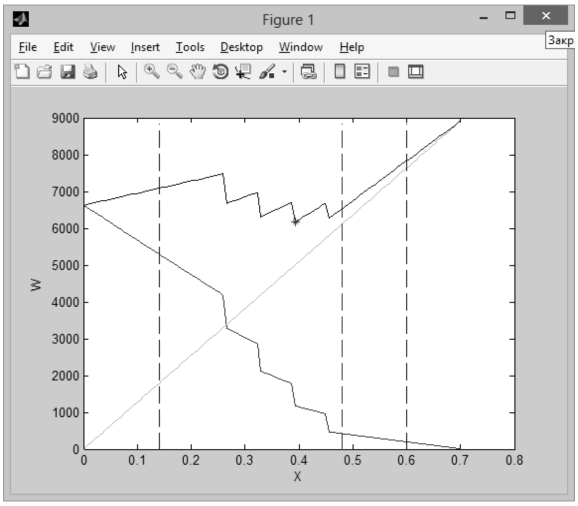

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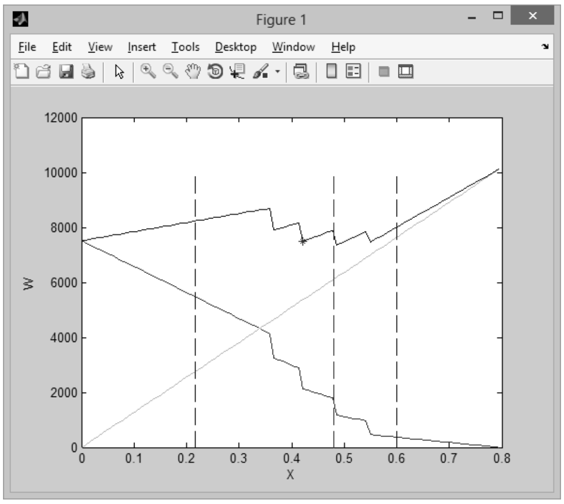

d

Fig. 5. The economic optimum cleaning pollutants in certain production volume:

a – the production of 40 units of output,

b – the production of 110 units of output,

c – the production of 168 units of output,

d – the production of 225 units of output

– costs of dumping pollutant (solid right),
– cost of cleaning (solid left),
– total cost (solid upper),
– limit possible discharge (dotted external),
– technical cleaning capability (dotted internal),
* – searching optimal volume cleaning X_{opt}

For typical in recent years production volume of 110 units and existing treatment plant capacity the optimum level of cleaning is 0.24 tons, 0.57 tons of pollution formed. In this situation, enterprise pays a tax rate increased 2-fold, the total cost is 4200 UAH. (Fig. 5b). Situation with increased production volumes modeled. Optimum approaching to the border treatment plants technological cleaning capabilities (Fig. 5c). With an increase in production to 225 units optimal cleaning is 0.49 tpa, but the this optimum is out of reach because of treatment plants technological cleaning capabilities limited opportunities in 0.48 tons. Enterprise pays ecological tax increased 3 times, total costs are 7500 UAH (Fig. 5d). It needs additional installation or upgrade existing treatment facilities.

With production volume to 40 units of output for enterprise it economically does not cleaning the pollutants because of their MAC standards allowable concentration (Fig. 6).

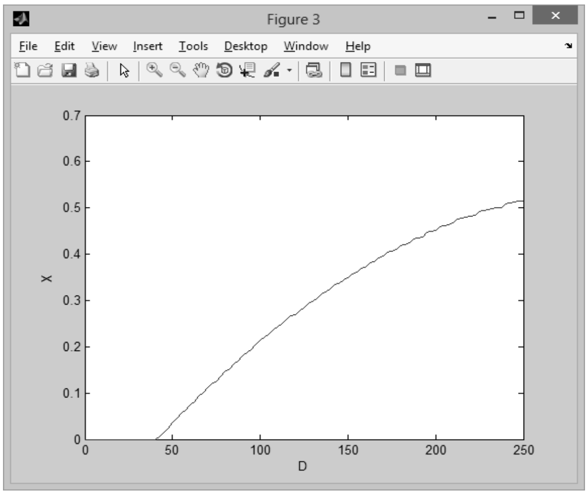

Fig. 6. The dependence of the economically optimal level of pollutants cleaning X and production volume D

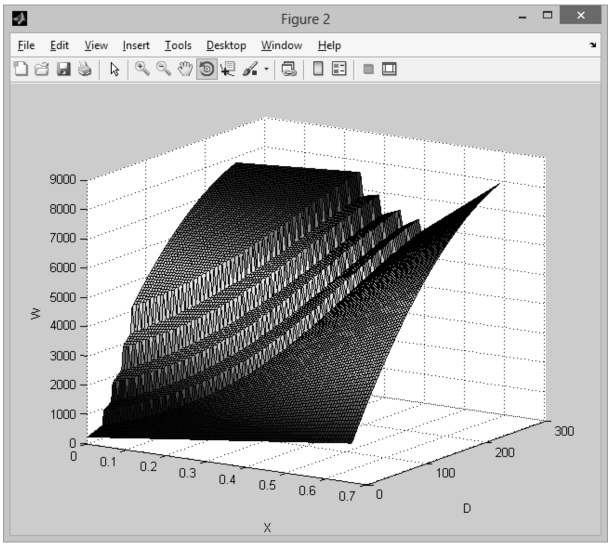

Fig. 7. Three-dimensional graphics costs for water use of the enterprise depending on production volume and cleansing of pollution

It can be used in planning environmental protection measures at increasing production capacity to identify the need for further purification formed pollution.

In Fig. 7 surface, which characterizes the change in costs on water use is shown.

From an environmental and economic point of view optimal is such volume pollution cleansing that allows pay for regular tax rate, it is form the first chute surface. The cost of treatment is higher than the cost of polluted, making economically profitable to pay increasing environmental tax (2nd and 3rd chute surface) worsening state of the environment than to install a powerful and wastewater treatment system.

CONCLUSIONS

1. Economic-mathematical model building and its program realization by means of MATLAB had given simulation opportunity of dependence of costs of wastewater treatment and planning production volume, taking into account the existing treatment facilities technical capabilities, allowable discharge of pollutants and environmental taxes.

2. Results of research can be used for strategic and operational ecologico-economic management in order to exercise eco-directional control at industrial enterprise.

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ЭКОНОМИКО-МАТЕМАТИЧЕСКОЕ МОДЕЛИРОВАНИЕ РАЦИОНАЛЬНОГО ВОДОПОЛЬЗОВАНИЯ И МИНИМИЗАЦИИ НЕГАТИВНОГО ВЛИЯНИЯ МАШИНОСТРОИТЕЛЬНОГО ПРЕДПРИЯТИЯ НА ОКРУЖАЮЩУЮ СРЕДУ

Султан Рамазанов, Анна Воронова

Аннотация. В статье рассматривается применения экономико-математического моделирования для обеспечения экологически направленного управления для промышленных предприятий. Исследование проводилось на примере машиностроительного предприятия "Луганскетпловоз" в части обеспечения эффективного водопользования в сфере промышленного производства и минимизации негативного влияния его деятельности на природную среду. Построена экономико-математическая модель поиска экономического оптимума очистки загрязнений водных ресурсов при осуществлении производственной деятельности предприятием.
Ключевые слова: промышленное предприятие, водообеспечение производства, нерациональное природопользование, загрязнение окружающей среды, экономические и экологические убытки, экономико-математическое моделирование, экологически направленное управление.